Marine Policy 103 (2019) 121–129

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Stakeholder perceptions of climate change in the context of bivalve aquaculture

L. Steeves[a,*], R. Filgueira[a,b]

[a] Department of Biology, Dalhousie University, 1355 Oxford Street, Halifax, NS, B3H 4R2, Canada.
[b] Marine Affairs, Dalhousie University, 1355 Oxford Street, Halifax, NS, B3H 4R2, Canada

ARTICLE INFO

Keywords:
Aquaculture
Bivalves
Climate change
Stakeholders
Perceptions
Q methodology

ABSTRACT

Climate change, observed as warming sea surface temperatures, is expected to impact the Eastern coast of Canada at a rate higher than the global average. Changes in marine abiotic conditions will impact the growth and performance of economically important bivalve species, creating an increasingly uncertain future for the bivalve aquaculture industry. Site-selection for new farms, and the management of extant ones could mitigate these potential impacts, but the implementation of this planning process is dependent on stakeholder support and engagement. Recognizing the importance of stakeholder input in management decisions, this research analyzed the perspectives of farmers, researchers, and managers from Nova Scotia (NS) and Prince Edward Island (PEI) on the relationship between climate change and bivalve aquaculture. Stakeholder perspectives were analyzed using a semi-quantitative interview method (Q methodology). These perspectives indicated the need for a higher level of integration both between stakeholder groups, namely farmers and managers, and management tools and climate change. Increased understanding between farmers and managers could be achieved through the use of researchers as knowledge brokers, collaborating and communicating with both groups. Making use of management tools, such as the ecosystem approach to aquaculture, required insurance, and adaptive management, governmental bodies on both a federal and provincial level can act as channels by which uncertainty generated by climate change can be further reduced. In summary, stakeholder perception can be used by marine planners to adapt to these foreseen changes, and to promote the expansion of this industry.

1. Introduction

Globally, climate change is altering abiotic properties of our oceans, and subsequently the living conditions for aquatic organisms [1,2]. Specifically, warming ocean temperatures combined with increased acidification and storm frequency may create new opportunities and threats for the bivalve aquaculture industry [3]. For example, changing sea surface temperatures (SST) are having observable effects on the distribution of economically important bivalve species, such as mussels, oysters, and scallops (e.g. Ref. [4]). These ectothermic organisms are grown in marine aquaculture (mariculture) farms across the globe, and in 2015 over 14 million tonnes of bivalves were produced [5]. Climate change will impact how bivalves perform in terms of growth and survival, and subsequently determine where they can be cultured [6,7]. Filgueira et al. [8] have suggested that in coastal waters of Prince Edward Island (PEI) climate change projections will create growing conditions in which oysters may outperform mussels. Due to the dynamic nature of the interaction between bivalve aquaculture and climate change, the flexibility of stakeholders to develop shellfish mariculture in new and innovative ways may be required to maintain a viable industry [9].

Climate change is impacting Canada's coastlines at accelerated rates compared to global averages [10] and on the east coast of Canada sea and air temperatures are projected to continue to increase throughout the 21st century [2]. Currently, eroding shorelines, storm surges, and warming water temperatures are being observed, particularly in PEI [10–12]. These coastal impacts are driven by a multitude of processes including rising sea levels, reduced sea ice (both in thickness and duration), and an increase in frequency and strength of extreme weather events. Changes in temperature influences bivalve physiology; as ectotherms, changes in temperature impact basic functions such as heart and filtration rates [13,14]. Changes in temperature will therefore affect survival, phenology, and ultimately distribution [1,15]. The results of the relationship between temperature and bivalves is discussed widely in the body of scientific literature. For example, warming ocean temperatures are currently permitting the northward migration of

* Corresponding author.
E-mail address: laura.steeves@dal.ca (L. Steeves).

https://doi.org/10.1016/j.marpol.2019.02.024
Received 7 February 2018; Received in revised form 9 January 2019; Accepted 20 February 2019
Available online 02 March 2019
0308-597X/ © 2019 Elsevier Ltd. All rights reserved.

many marine species (e.g. Refs. [4,16–19]). Additionally, temperature may impact the timing of life cycle events (e.g. spawning and overall reproductive effort) which will have downstream effects on population growth and interspecific interactions [15,20,21]. Increased temperature has also been seen to promote the proliferation and possibility distribution of harmful protozoans associated with cultivated bivalves (e.g. *Haplosporidium nelson* (MSX)), as well as bacteria (e.g. Vibriosis) [3,6] Apart from temperature, climate change may impact bivalves in other ways. Increased storm frequency may alter both the shape and biological productivity of coastal embayments, having an impact on the primary food source of bivalves [11,22]. With shells made of calcium carbonate, spat survival and growth has been found to be negatively impacted by ocean acidification [23]. Impacts of climate change on bivalves are also often species specific (e.g. Refs. [8,15,16,18,21]), meaning that future conditions may have both positive and negative impacts, dependent on the species being farmed.

As stated above, the effects of climate change on bivalve aquaculture are commonly explored from a biological perspective (e.g Refs. [4,24]). However, in terms of industry development it is also relevant to understand how key stakeholders of bivalve aquaculture, ranging from farmers and regulators to academic researchers, understand and perceive the emerging relationship between bivalve aquaculture and climate change. Exploring stakeholder perceptions as they relate to aquaculture (e.g. Refs. [25–28]), and climate change (e.g. Refs. [29–31]) is an emerging topic in the literature. As mariculture relies on local conditions (e.g. water temperature), local knowledge within an industry has been recognized as important capital for aquaculture management [9]. Perspectives, as they relate to stakeholder groups, are useful input for successful and sustainable management of aquaculture [32]. Not understanding how stakeholders perceive management problems can lead to mismanaged resources and decreased public trust [33]. Furthermore, understanding the perceptions of stakeholders can assist governments in creating policies/mitigation strategies that are accepted by the consulted groups [32,34]. Although the body of social science literature on the topic of aquaculture and climate change is growing, often focus is placed on consumer and public groups [35–38]. Recent studies (e.g. Refs. [32,39]) instead focus on key stakeholders within the industry, to gain an in-depth understanding of the perceptions of a select group.

Vulnerability of coastal resources and livelihoods to climate change is highly spatially dependent because of both natural processes (e.g. climate), and local governance of coastal resources [40]. Bivalve aquaculture is an important economic contributor to Eastern Canadian provinces, in terms of revenue and job creation [41,42]. PEI is consistently Canada's largest producer of blue mussels, by both value and mass [43]. Additionally, Nova Scotia (NS) has almost doubled its production value of bivalve aquaculture between 1995 and 2015 [43], and recently, the provincial government has invested $2.8 million in aquaculture research and development [44]. Bivalve aquaculture contributes indirectly to the maritime economy through its provision of jobs in rural communities which tend to experience high levels of unemployment, and have few sources of year-round income [41,45]. For example, in NS in 2014, almost half of all employees of the aquaculture industry were working in the bivalve aquaculture industry [42].

The expansion and success of this industry is contextualized by our changing climate, how it will impact the industry, and what mitigation strategies are employed to ameliorate those impacts. Engaging with stakeholders is important in the planning process, both for the establishment of new farms, and renewing leases for active farms. Many stakeholders (e.g. farmers, researchers) have firsthand experiences with the effects of climate change. The experiences and perceptions that stakeholders have will be important for determining the willingness of farmers to move farm locations, switch the species that they are cultivating, or to accept the risk of investing in an economic activity that could be affected by a changing climate. This topic is particularly relevant for maritime provinces of Canada such as NS and PEI; it has been recognized that sea surface temperatures in these regions are increasing at a rate higher than the global average [2,46]. This research aims to determine how stakeholders perceive the relationship between climate change and shellfish farming in NS and PEI. This relationship was explored using a mixed method interview, Q methodology, with stakeholders from research, farming, and management backgrounds. This knowledge is useful for creating marine policy anticipating changes in bivalve farming in terms of adapting current sites (e.g. farming more thermally tolerant species) and new sites can be developed (e.g. in colder waters).

2. Materials and methods

Q methodology, originating in the field of psychology, is a semi-quantitative interview method, which has recently been applied to studies of both aquaculture [32,39,47] and climate change [48]. Q methodology is used for collecting data about diverse opinions on a single topic, as a way to assess the subjectivity of individuals [49,50]. Results help to define thematic perspectives on a topic, and groups participants based on how similar their responses were [51]. One of the strengths of Q methodology is that it does not require large sample sizes to produce significant results, as survey methods often do [52]. Q methodology aims for depth above breadth – it delves deeply into an individual's perception of a topic, but makes no statements about a broader population [51]. Similarly to traditional survey methods participants are presented with a number of statements that they must place on a form of a Likert scale [53], however each position on the scale has a limited number of spaces (Fig. 1). In total, there are only as many spaces as there are statements that must be ranked. Participants must rank statements against each other, to prioritize their answers. Once the sort is completed, statistical analyses are applied to interpret the prevailing discourses [54].

2.1. Concourse survey and selecting statements

Q methodology follows a set of discreet steps, as outlined by Du Plessis [52]. To begin, a concourse survey is conducted to provide the researcher with a comprehensive understanding of all of the range of opinions that exist on the topic at hand. The concourse survey entails a thorough review of the relevant literature on the topic and creating a list of all represented opinions. This was done by surveying both scientific and grey literature (e.g. peer-reviewed journal articles and newspaper articles, respectively), on the topic of climate change and bivalve aquaculture, with emphasis on Atlantic Canada. Once the concourse survey had saturated all existing perceptions on the topic, repeated opinions were removed from the list of statements, so no views were represented more than once. Next, the statements were grouped into categories by relevance: 1. Climate change 2. Shellfish biology and

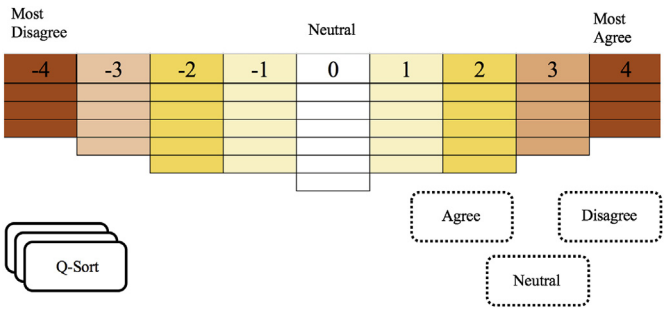

Fig. 1. Q Methodology interview set-up. Participants read through the deck of Q-sort cards (n = 40), dividing them into piles of "agree" "disagree" and "neutral." Piles were then further subdivided onto the matrix, based upon subjective rankings of the statements by the participant (Adapted from Ref. [39]).

Table 1
Q-sort statements (n = 40) used in the Q methodology interview, organized by corresponding categories.

Category	Statement
Climate Change	1. Warming of oceans has been accelerated in recent history
	2. There is no scientific consensus that climate change is occurring
Shellfish Biology and Climate Change	3. Warming ocean temperatures will not have an impact on the growth rate of shellfish species
	4. Ocean temperatures will not warm enough to impact shellfish distribution
	5. Warming ocean temperatures will not have an impact on the mortality rates of shellfish species
	6. Increased water temperatures have no relationship to the presence or abundance of invasive tunicates
	7. There is no relationship between warming ocean temperature and an increase in frequency of harmful algal blooms
	8. Increased water temperatures will not lengthen the growing season for shellfish
	9. Ocean acidification is having a negative impact on the survival of marine shellfish larvae
	10. Warmer water temperatures will cause an increase in the frequency of MSX outbreaks
	11. Climate change will be related to new kinds of disease outbreaks on shellfish farms
	12. Shorter/warmer winters will decrease mortality rates for some shellfish species
	13. Longer/warmer summers will increase mortality rates for some shellfish species
	14. Increased and intensified storms will cause increased run-off that may negatively impact shellfish
	15. Increased temperature will cause suppressed immune system function in some shellfish
	16.The effects of climate change on shellfish farming are too uncertain to accurately predict
	17. Climate change will alter the timing of food availability and food requirements for some shellfish species
Farming Costs	18. Climate change will increase the costs of shellfish farming
	19. Climate change will not impact the cost of operating a shellfish farm
	20. Climate change impacts will have no impact on the price of shellfish spat
	21. The market price of shellfish will be unaffected by warming ocean temperatures
	22. As water temperatures warm, the cost needed to produce shellfish will decrease
	23. Climate change will cause an increase in insurance costs for shellfish farming
Farming Logistics	24.Water temperatures warming beyond the tolerable ranges of shellfish species will cause the closure of currently operating farms in some areas
	25. Warmer water temperatures will permit the opening of new shellfish farms where previously the water was too cold to do so
	26. Emergency response plans to extreme storm events will be increasingly necessary in the coming years for shellfish farms
	27. It would be unlikely that a farm should move to a new location because of the effects of climate change
	28. Farm management plans should not consider the predicted effects of climate change
	29. Risk associated with climate change should be integrated into new lease proposals
Role of Policy and Government	30. Leasing applications should not have to consider the expected water temperature changes in the area
	31. The government should compensate shellfish farmers for their positive effects on the environment
	32. Adaptation measures for shellfish farms to deal with climate change conditions must be created at the bay scale
	33. When planning for new shellfish farms, it is not necessary to consider climate change
	34. The government should prioritize shellfish research on invasive tunicates
	35. The government should prioritize shellfish research on the ability of shellfish species to adapt to climate change conditions
	36. The government should prioritize shellfish research on shellfish disease risk in response to climate change
	37. The government should prioritize shellfish research on technology to prevent predation (i.e. sea ducks)
	38. The government should prioritize shellfish research on seed security and domestication
	39. The government should prioritize shellfish research on the risk of MSX and Vibrio parahaemolytics
	40. In light of climate change, the government should promote shellfish farming as an industry with positive environmental impacts

climate change 3. Farming cost 4. Farming logistics and 5. Roles of government and policy. In order to work with a manageable number of statements, similar statements were combined. Statements were also balanced to reflect pro, neutral, and con opinions about the topic. There final grouping of statements is termed the Q-Sort, and for this study contained 40 statements (Table 1).

2.2. Survey participants

Participants were identified and selected for this reached based upon two criteria, 1. That they were stakeholders in the bivalve aquaculture industry in NS or PEI and 2. That they related to the bivalve aquaculture industry in diverse ways. Participants were grouped based on their stakeholder role into three categories: 1. Shellfish farmers (n = 6) 2. Shellfish researchers (n = 10) and 3. Managers (including policy-makers/regulators) (n = 4). Although other stakeholder groups could be identified (e.g. consumers, retailers), this study aims to inform management/regulations, and they were therefore excluded. The number of participants (n = 20) fits within the standard of the literature (e.g. Refs. [39,55,56].

2.3. Q methodology interviews

Q methodology interviews were conducted from June 2017–September 2017, with the approval of the Dalhousie Research and Ethics Board (REB-2017-4125). These interviews were face-to-face and took place at locations chosen by the participants. To begin, participants read through the Q-sort statements (Table 1) which were randomly numbered and then printed out on individual index cards (Fig. 1). Numbering ensured that all participants read the statements in the same order. After reading each card, the participant was encouraged to sort it into a pile based on whether or not they agreed, disagreed, or felt neutral about the statement. Next, each card in the Q-sort was further sorted onto a grid chart (Fig. 1), which ranged from −4 (most disagree) to + 4 (most agree), where 0 represented neutrality. This grid is a forced “quasi-normal” distribution, where participants must rank statements against each other to determine the perspectives they feel the most strongly about. The grid contains exactly as many cells as Q-sort statements, therefore all statements must be ranked, and no cell is left without a statement [57]. The finalized placement of statements on the board for each participant is referred to as their Q-sort. Once the participant had finalized their Q-sort, there was an opportunity for him/her to discuss their choices with the researcher. This information contextualized the rationale of participants and was used in interpretation of the results.

2.4. Statistical analyses

All Q-sorts were analyzed in the statistical software PQMethod 2.35 [54], to find patterns in responses both between and within stakeholder groups. The interview data were imported into the PQMethod software and a factor analysis was performed [54]. First, to determine how

correlated the Q-sorts were, a correlation matrix was created where a correlation of 1 represents two participants who sorted the statements identically. Next, a principal component analysis (PCA) was done to group similar Q-sorts together using the correlation matrix. These groups are statistically referred to as "factors", which represent groups of participants who had similar perspectives about climate change and shellfish farming [56]. These factors (hereafter referred to as perspectives) were rotated using varimax orthogonal rotation to determine which perspectives explained most of the variance in the data. Although many perspectives can be produced, only those which are statistically relevant were chosen to be further analyzed. To meet these criteria, only perspectives which explained > 10% of the variance in the data and had eigenvalues of > 2.00 (e.g. at least two Q-sorts correlated significantly with each other), were chosen.

To begin the factor analysis, an idealized Q-sort is created for each perspective, which was done using an averaged of all Q-sorts which loaded significantly for that perspective [58]. Using this idealized sort, another correlation matrix was made between each participant, and the perspective with which they were most closely correlated. To determine if the factor loadings for each participant were significant upon a perspective, the following equation was used:

$$s = 2.58 * (\frac{1}{\sqrt{N}}) \quad (1)$$

Where N is the number of statements [57], producing an s of 0.4 at the 0.1 level of significance [49]. This significance level was then increase to 0.5, a method used by other authors (e.g. Ref. [39]), to create more stringent criteria. Perspectives were then analyzed qualitatively, to determine if the statements contained within each perspective were logical groupings ([39]). Confounding Q-sorts were those in which participants loaded significantly either on multiple factors, or no factors.

3. Results

Three distinct perspectives emerged from the factor analysis of the Q-sort. Cumulatively, these perceptions explained over 68% of the variance between the 20 Q-sorts (Table 2) (P1 = 32%, P2 = 11%, P3 = 25%). These perspectives indicated that all stakeholders interviewed can be grouped into three categories, each with distinct perceptions about bivalve aquaculture and climate change. All stakeholders grouped significantly into at least one perspective, and three stakeholders were grouped into two perspectives (i.e. confounding sorts) (Table 2). For each perspective, an "idealized sort" was created, indicating where each Q-statement would be sorted if the stakeholder fit perfectly with that perspective (Table 3). The following sections list areas of consensus between all stakeholders, and analyze each perspective, based upon its idealized sort, and the stakeholders who matched significantly with it. To ensure that only statements which stakeholders felt strongly about are being interpreted, only extreme statements (ranked −4, −3, +3, +4), and distinguishing statements (p-values < 0.05), will be discussed in relation to each factor. Interpretations of perspectives will be supported by statement numbers indicated in parentheses (e.g. (12)). Perspectives were given titles, interpreted from their idealized sorts, and are as follows: Perspective 1: The Theorist, Perspective 2: The Pragmatist, and Perspective 3: The Middle Ground.

3.1. Areas of consensus

Statements that were not ranked significantly different between perspectives were not used as defining statements, and instead are termed areas of consensus. Eight statements were non-significant for all perspectives at p > 0.05, meaning that these statements could not be used to define any perspective, because all groups felt similarly. All perspectives felt strongly that the government should prioritize shellfish research on both seed security (38), and the ability of shellfish to adapt to climate change (35). Furthermore, all perspectives agreed that warming water temperatures would impact shellfish growth rates (3). All perspectives thought that climate change would impact the cost of operating a farm (19), however the directionality of this impact was unclear (18). It was either unclear, or neutral, to all stakeholders whether or not farms would have to move to new locations because of climate change (27). Finally, the link between climate change and disease outbreaks was mostly unclear to all stakeholders (10, 11) with statements about diseases being sorted into 0, +1, or +2 by all groups.

Table 2
Summary of Q-sort factor loadings. Values of −1 and +1 represent complete disagreement and complete agreement, respectively. Bold numbers represent significant values (factor loading coefficient > 0.5).

Stakeholder	P1	P2	P3
Perspective 1 (P1)			
Manager	**0.8304**	0.0710	0.2367
Manager	**0.7235**	0.2230	0.4708
Researcher	**0.7160**	−0.0161	0.3278
Researcher	**0.7231**	0.1714	0.4191
Researcher	**0.7337**	0.4011	0.2462
Researcher	**0.7388**	0.4077	0.1840
Researcher	**0.7515**	0.1855	0.3447
Researcher	**0.5420**	−0.0194	0.4169
Manager	**0.6853**	0.2506	0.4987
Perspective 2 (P2)			
Farmer	0.0684	**0.7689**	0.0800
Researcher	0.4541	**0.5254**	0.3088
Perspective 3 (P3)			
Farmer	0.3938	−0.2588	**0.5285**
Farmer	0.2625	0.4648	**0.6201**
Researcher	0.3656	0.1687	**0.7963**
Researcher	0.3779	0.2176	**0.6942**
Farmer	0.4275	0.2975	**0.6700**
Researcher	0.3067	0.2152	**0.7686**
Confounding Sorts			
Manager	**0.5316**	0.1237	**0.6188**
Farmer	**0.6636**	0.1979	**0.5226**
Farmer	0.1638	**0.5252**	**0.5669**
Explained Variance (%)	32	11	25
Total Defining Q-Sorts	9	2	6
Total Q-Sorts	11	3	10

3.2. Perspective 1: The Theorist

The Theorist perspective was most concerned with long-term impacts of climate change on shellfish biology. To begin, this perspective strongly agrees that climate change is impacting ocean temperatures at an accelerated rate (1, 2). This group is most concerned about the effects of warming temperatures on shellfish biology, particularly increased growth and mortality rates (3, 4, 5). Furthermore, this was the only group that felt strongly that warming ocean temperatures had the potential to close currently operating farms in some regions (24), and also to create opportunities to open new farms in areas that were previously too cold to do so due to impacts on bivalve physiology (25). Furthermore, this perspective thought that the government should prioritize research on the ability of bivalves to adapt to climate change conditions (35). This group did not feel strongly about any statements related to price (21), however they did agree that climate change will alter the price of shellfish spat (20). Stakeholders in this group believed most strongly of all the perspectives that farm planning should consider the predicted effects of climate change (28, 33, 30). Additionally, this group did not hold strong opinions on the potential to compensate farmers/promote shellfish farming for its positive environmental impacts (31, 40). This group also felt the most strongly that when planning

Table 3
Idealized sort for each perspective descried by each category of Q-statements. * = significant at p < 0.05 ** = significant at p < 0.01.

Category	Statement	P1	P2	P3
Climate Change				
	1. Warming of oceans has been accelerated in recent history	4	1**	4
	2. There is no scientific consensus that climate change is occurring	−4	−2**	−4
Shellfish Biology and Climate Change				
	3. Warming ocean temperatures will not have an impact on the growth rate of shellfish species	−4	−2	−3
	4. Ocean temperatures will not warm enough to impact shellfish distribution	−3	0**	−3
	5. Warming ocean temperatures will not have an impact on the mortality rates of shellfish species	−4**	−2	−2
	6. Increased water temperatures have no relationship to the presence or abundance of invasive tunicates	−2*	−4	−4
	7. There is no relationship between warming ocean temperature and an increase in frequency of harmful algal blooms	−3	−4	−4
	8. Increased water temperatures will not lengthen the growing season for shellfish	−1	2**	−2
	9. Ocean acidification is having a negative impact on the survival of marine shellfish larvae	3	4	3
	10. Warmer water temperatures will cause an increase in the frequency of MSX outbreaks	0	2	1
	11. Climate change will be related to new kinds of disease outbreaks on shellfish farms	1	1	2
	12. Shorter/warmer winters will decrease mortality rates for some shellfish species	−1	2	0
	13. Longer/warmer summers will increase mortality rates for some shellfish species	1	−2**	1
	14.Increased and intensified storms will cause increased run-off that may negatively impact shellfish	2	3*	2
	15. Increased temperature will cause suppressed immune system function in some shellfish predict	1	−1**	1
	16. The effects of climate change on shellfish farming are too uncertain to accurately	0	−1	0
	17. Climate change will alter the timing of food availability and food requirements for some shellfish species	2	0*	3
Farming Costs				
	18. Climate change will increase the costs of shellfish farming	0	1	1
	19. Climate change will not impact the cost of operating a shellfish farm	−2	−3	−2
	20. Climate change impacts will have no impact on the price of shellfish spat	−2*	−4	−3
	21. The market price of shellfish will be unaffected by warming ocean temperatures	−2	0**	−2
	22. As water temperatures warm, the cost needed to produce shellfish will decrease	−1*	−3	−3
	23. Climate change will cause an increase in insurance costs for shellfish farming	0	−3**	0
Farming Logistics				
	24. Water temperatures warming beyond the tolerable ranges of shellfish species will cause the closure of currently operating farms in some areas	4**	−1	0
	25. Warmer water temperatures will permit the opening of new shellfish farms where previously the water was too cold to do so	3*	1	1
	26. Emergency response plans to extreme storm events will be increasingly necessary in the coming years for shellfish farms	2	2	0*
	27. It would be unlikely that a farm should move to a new location because of the effects of climate change	−1	0	−1
	28. Farm management plans should not consider the predicted effects of climate change	−3	−3	−1*
	2229. Risk associated with climate change should be integrated into new lease proposals	2**	−2*	−1*
Role of Policy and Government				
	30. Leasing applications should not have to consider the expected water temperature changes in the area	−2	−1	−1
	31. The government should compensate shellfish farmers for their positive effects on the environment	−1	3**	0
	32. Adaptation measures for shellfish farms to deal with climate change conditions must be created at the bay scale	−1	4**	−1**
	33. When planning for new shellfish farms, it is not necessary to consider climate change	−3**	1**	−2**
	34. The government should prioritize shellfish research on invasive tunicates	0*	0*	3**
	35. The government should prioritize shellfish research on the ability of shellfish species to adapt to climate change conditions	4	2	3
	36. The government should prioritize shellfish research on shellfish disease risk in response to climate change	3	−1**	2
	37. The government should prioritize shellfish research on technology to prevent predation (i.e. sea ducks)	0**	3	2
	38. The government should prioritize shellfish research on seed security and domestication	3	3	4
	39. The government should prioritize shellfish research on the risk of MSX and Vibrio parahaemolytics	1*	0*	4**
	40.In light of climate change, the government should promote shellfish farming as an industry with positive environmental impacts	1	4**	2

for new sites, climate change should be considered (30). The most stakeholders were sorted into this perspective, six researchers and three managers.

3.3. Perspective 2: The Pragmatist

Stakeholders in the Pragmatist perspective seemed to perceive climate change as less of an immediate threat to shellfish farming, and therefore saw fewer opportunities for mitigation strategies. This group viewed climate change as occurring, but not as important an issue as other perspectives (1, 2). However, strong links were made between increased water temperature and invasive tunicates (6), as well as harmful algal blooms (7). This group also recognized the importance of storm runoff as having potential to negatively impact shellfish (14). Apart from acidification (9), this group felt the most neutral about the effects of climate change directly on bivalve physiology (e.g. 4, 8). This group felt the most strongly that climate change would impact the price of spat (20). Regarding the role of policy/government, this group agreed the most that shellfish farmers should be compensated for their positive effects on the environment (31), and similarly that the government should promote shellfish farming as an industry with positive environmental impacts (40). Stakeholders in this group did not believe that research should focus on disease risk and climate change (36), but instead should focus on seed security and domestication/as well as predation mitigation (9, 38). This was the only group that felt strongly that climate change would not increase the insurance costs for shellfish farming (23), and that adaptation measures for farms to deal with climate change should be created at the bay scale (32). Only two stakeholders were grouped in this perspective, one researcher and farmer.

3.4. Perspective 3: The Middle Ground

The Middle Ground perspective recognized diverse impacts of climate change on bivalve farming, however they prioritized the impacts differently than the first perspective. This group strongly agrees that climate change is impacting ocean temperatures at an accelerated rate (1, 2). Furthermore, this group saw the effects of increased water temperatures as having similar effects on shellfish biology (4, 9), as the first perspective, although they viewed them as slightly less important. Instead, this group more strongly agreed with the effect of warming water temperatures on the presence/abundance of invasive tunicates (6), harmful algal blooms (7), and the timing of food availability (17). In terms of cost, this group saw climate change as having potential to impact the price of spat (20), and that generally as water temperatures increase, the cost needed to produce shellfish will also increase (22). This group did not feel strongly about the need to integrate climate

change risk/impacts into lease proposals or farm management plans (28, 30). Of all groups, this perspective felt that most strongly that the government should prioritize research on MSX and *Vbirio* (39), and the impact of invasive tunicates (34). Three farmers and three researchers were sorted into this perspective.

3.5. Confounding sorts

Not all stakeholders were clearly sorted into one perspective (Table 2). These sorts are called confounding sorts and represent stakeholders who shared perspectives of two or more groups. Three confounding sorts were identified, one manager and one farmer overlapping with perspective 1 and 3, and one farmer overlapping with perspective 2 and 3 (Table 2).

4. Discussion

Stakeholder perspectives have long been viewed as important input in policy creation processes for aquaculture [34]. Often, stakeholders hold diverse opinions which can be difficult to capture. Q methodology provides a way to explore how stakeholders group together, based not on occupation, but by their perceptions on a topic [51]. This research explored how stakeholders understand the relationship between climate change and bivalve aquaculture in NS and PEI. As two provinces with extensive capacity for bivalve aquaculture [59], the successful management of this industry should reduce uncertainties generated by climate change and identified by stakeholders.

4.1. Manager-farmer divide

The perspectives found from this research provide information about overlap (or lack thereof) between farmers, researchers, and managers. Notably, some perspectives lacked certain stakeholders, which may be indicative of topics most relevant to each perspective. Perspective 1 (The Theorist) contained the majority of stakeholders (n = 9), however no farmers were sorted solely into this group. Despite this, one farmer was sorted significantly into both Perspective 1 and 3 (i.e. a confounding sort) (Table 2). Furthermore, Perspective 1 placed the most emphasis on the importance of climate change impacts to shellfish biology. Perspective 3 (The Middle Ground) had the second largest grouping of stakeholders (n = 6) and notably no managers were sorted only into this group, however there was one confounding sort containing a manager in both perspective 3 and 1 (Table 2). Perspective 3 recognized the importance of both short- and long-term impacts of climate change on biology. Perspective 2 (The Pragmatist) contained just one farmer and one researcher, and of the three significant perspectives identified using Q methodology, viewed the impacts of climate change on shellfish biology as the least important. Additionally, one confounding sort, a farmer, was sorted into both Perspective 2 and 3 (Table 2). With the exception of two confounding sorts (Table 2), none of the farmers or managers interviewed shared perspectives on climate change and bivalve aquaculture.

These results suggest that there is a potential disconnect between the perceptions of managers and farmers, in terms of their understanding of the relationship between bivalve aquaculture and climate change. The discourse between resource users and policy-makers is particularly important for the development of an industry in times of increasing uncertainty [60].

Bridging the knowledge gap between managers and farmers may require a knowledge broker, or a person/organization whose responsibility it is to mobilize information from researchers to user groups [61]. Knowledge brokers often exist at the boundaries of organizations, for example, where policy ends, and farming begins [62]. Although knowledge brokers cannot be excepted to solve all the problems at this interface, they have been shown to assist with increasing trust between two ideologically divided groups [61,62]. This study shows that researchers (governmental, academic, and industrial) have the potential to act as knowledge brokers between managers and farmers.

4.2. Climate change and shellfish biology

Stakeholders generally agreed with the mounting evidence surrounding climate change, and its effects on shellfish biology. All stakeholders acknowledged that the processes of climate change are important for any further exploration of its effect on shellfish farming. All stakeholders recognized that changing water temperatures will impact shellfish growth rates (3), and the impacts of ocean acidification on spat survival (9). Only the two stakeholders sorted into Perspective 2 (The Pragmatist) felt neutrally, or slightly supportive of these ideas. What divided stakeholders on these issues was not recognizing processes, but to what extent they were important. Perspective 1 ranked effects on shellfish biology as highest, Perspective 3 in the middle, and Perspective 2 felt the least strongly about these statements in general. For example, the idea that warming ocean temperatures would warm enough to impact shellfish distribution (4), Perspective 2 felt neutrally about, whereas the other two perspectives strongly supported. Variable ranking may indicate that some stakeholders place priority on immediate and observable impacts, as opposed to long-term impacts. Interestingly, managers sorted primarily into Perspective 1, representing longer-term effects, such as temperatures related impacts to shellfish mortality and growth rates (3, 5). Contrastingly, farmers who mostly aligned with Perspective 2 and 3, placing a greater concern on immediate impacts, such as harmful algal blooms and tunicate abundance (7, 6). This people-policy gap is not uncommon for aquaculture [63,64], and is another area that could benefit from a knowledge broker.

4.3. Stakeholder uncertainty and resulting risk

Statements which were sorted similarly by all stakeholders into low rankings (i.e -2 -1 0 +1 +2), may be interpreted as areas of uncertainty. These were statements which stakeholders either did not feel strongly about or felt they did not have enough information to make an informed decision about the relationship stated on the card [39,51]. For example, all perspectives ranked the statement “Warmer water temperatures will cause an increase in the frequency of MSX outbreaks” (10) either as 0, +1, or +2 (Table 3). MSX, a disease which *C. virginica* is susceptible to, has been identified as a research priority for the Department of Fisheries and Oceans Canada, and has as well been discussed in the media as a major concern for farmers [65]. It is therefore unlikely that the median ranking of this statement represents neutrality on the subject, but an uncertainty about the relationship between MSX and temperature (10).

Other statements which may indicate uncertainty from stakeholders primarily related to either farming practices, planning, or cost. In contrast to the impacts of climate change on shellfish biology, these relationships appear much less clear. Although most stakeholders believed that climate change will increase the price of spat (20), it was not clear to any stakeholders if climate change would impact the market price of shellfish (21), or if climate change would impact the price of farming (18). Regarding farm planning, most researchers and managers felt strongly that climate change has the capability to both close currently operating farms (24), and create opportunities to open new farms (25), however no farmers supported these notions. Furthermore, no stakeholders were certain about the possibility of moving a currently operating farm to avoid the impacts of climate change (27). No stakeholders held strong opinions about the need to integrate potential risk associated with climate change (29) or expected water temperature changes (30) into lease proposals. As previously mentioned, the neutral ranking of these statements may indicate that stakeholders either do not believe them to be important topics, or that they do not have sufficient knowledge to rank the statement. If the latter is true, it may indicate

stakeholder uncertainty, which can pose risks to the shellfish farming industry.

4.4. Managing the effects of climate change on aquaculture

It has been recognized that global aquaculture industries will be impacted by climate change, and that those impacts will be specific to both location, culture method, and culture species [3,66]. By employing a set of synergistic management tools, it will be possible to reduce uncertainties and create a more resilient industry [3]. By reducing uncertainty, these tools aim to decrease the risk that stakeholders incur by investing in an industry expected to be impacted by climate change [67]. The following paragraphs outline management tools that can be used to manage aquaculture in the context of climate change. These management tools: ecosystem approach to aquaculture, required insurance, and adaptive management, are recognized on an international level by the Food and Agricultural Organization [3] and on a national level in Canada by the Department of Fisheries and Oceans Canada [68], however provincial legislation also plays a large role in aquaculture management in Canada.

The ecosystem approach to aquaculture (EAA) emphasizes the importance of integrating aquaculture practices into their surrounding ecosystem to support sustainable practices between ecological and social systems [69]. EAA requires the input of stakeholder experiences and attitudes to manage aquaculture [3]. EAA also emphasizes the need to manage resources on a waterbody scale, which was identified by Perspective 2 as being important for planning for climate change impacts (32). Managing at this scale would promote effective use of management programs such as biosecurity, and water monitoring at clustered levels, which may be beneficial for small-scale farming activities [3]. The overall concern that stakeholders indicated for the effects of climate change on shellfish biology, namely growth rate (3) and distribution (4), would be encapsulated by EAA by linking climate change drivers to ecological impacts. This is particularly relevant for concerns relating to ocean acidification and spat survival (9), and shellfish mortality rates (5). EAA could also address the possibility that farmers and researchers raised about opening farms in new areas (25), and closing currently operating farms (24), due to warming ocean temperatures. In 2009, DFO referenced ecosystem-based management and integrated management of aquaculture as two of the defining principles of aquaculture management in Canada [68]. Despite this, climate change is not mentioned explicitly as a part of either of these management approaches. A recent review found that two of the biggest barriers to implementing the EAA are legislation and regulation [70], indicating that change must occur at these levels for successful implementation. In Atlantic Canada, this means change at both the provincial and federal levels. For example, to address the possibility of opening farms in new areas (25), and the closure of currently operating farms (24) due to warming ocean temperatures, predictive models could be used to recommend areas well suited to opening new farms. This would require input on both predicted environmental changes (water temperature, food availability), but also on the biology of the species being grown [71]. This research could be conducted through provincial research programs such as the Aquaculture Research and Development Program in Nova Scotia, or federal programs such as the Program for Aquaculture Regulatory Research.

Insurance, or purchasing financial compensation to prepare for potential loss, has long been used to manage risk. Recently, it has been suggested as a mechanism by which risks incurred by aquaculturists can be mitigated [3]. At the industrial scale, for widely produced species (e.g. salmon) aquaculture insurance is well established [3], however for small scale operations, insurance is often not required or economically feasible [3]. The risk for damage to/loss of property may become intensified in the future, in association with increased storm frequency and intensity predicted as a result of climate change [10]. Interviewed stakeholders acknowledge the possibility of storms becoming more frequent and intense (14, 26), however these statements were not ranked above a +2 for any perspective. Several stakeholders mentioned during the interview that insurance often was not available for shellfish farming. Interestingly, the majority of stakeholders (Perspectives 1 and 3), ranked the statement about how climate change will impact insurance costs for shellfish farming (23) at zero, indicating they did not know how it would be impacted, or that it was not an important consideration. Currently in PEI and NS, insurance is not mandatory, or often available for shellfish farmers. In the past, severe storms such as the category 2 hurricane that made landfall in NS in 2003 have caused serious setbacks for shellfish farmers (Purdy, pers. Comm.). With the prediction that these kinds of storms may become more frequent [3,10], and that prediction being supported by stakeholders (14, 26), insurance could protect small scale farmers from incurring the burden of loss. This adaptive response to climate change would limit bankruptcies in the aquaculture industry, and help to minimize impacts to livelihoods [3]. At the national level, making insurance more easily available to the aquaculture industry has been suggested as a mitigation strategy for predicted impacts of climate change (23) [10]. This could be addressed in a similar way to insurance for the agriculture industry in Canada, which uses federal aid to minimize economic impact on farmers in the event of crop losses from natural hazards (the Farm Income Protection Act). At the provincial level, the government could provide information to new farmers about access to insurance, and the benefits it provides. Further, local associations could disseminate information about insurance policies through workshops and conferences, such as those organized by the Aquaculture Association of Nova Scotia.

Adaptive management is a tool applied to the management of natural resources which uses cyclical decision making in the face of uncertainty, to effectively improve management techniques over time [72]. Adaptive management is particularly well suited to deal with natural systems impacted by climate change [73], as the changes experienced by these systems have the potential to impact natural variability [67]. An iterative process, adaptive management is also able to address both short- and long-term considerations. This research identified a temporal divide between how stakeholders consider the impacts of climate change. Generally, people agreed that impacts would occur, but differences between perspectives reflected that some stakeholders were more concerned with more immediate effects, and others on the long-term. As discussed, Perspective 2 placed emphasis on observable impacts to shellfish farming such as tunicate abundance (6) and harmful algal blooms (7), whereas Perspective 1 showed greater concern for the future impacts of temperature change on shellfish growth (3). The concern for impacts of climate change to shellfish farming over a variable timescale indicates the usefulness for adaptive management. This temporal mismatch is often observed at the science-policy interface [63], and further explains the divide between resource managers and resource users (e.g. the farmer-manager divide observed in this study).

Adaptive management, and in particular monitoring, could help to prepare the industry to face climate change [67]. As climate change will have impacts previously unexperienced by both resources users, and affected species, monitoring will assist with recording when and what those effects are [67]. Stakeholders in this study acknowledged the uncertainty they have regarding how the industry will be impacted by climate change, for example in terms of spreading diseases (11), and in terms of farm operating costs (19). Information from monitoring programs, observations from farmers, and knowledge generated by researchers could be collected on these topics to inform adaptive management and ultimately policy decisions that benefit industry. For example, increased mortality rates of mussels have been observed by farmers in PEI in occurrence with prolonged high water temperatures, researchers are currently exploring the effect of temperature on bivalve performance [74], and stakeholders in this study identified this relationship as a concern (5). Anticipating summer heatwaves and effectively mobilizing this knowledge into an adaptive management

framework is key to bridging the science-policy gap towards effective regulations. Potentially, impacts from summer heatwaves could be mitigated by 1. Growing mussels and cooler water (24) or 2. Amending leases so farmers can cultivate more thermally tolerant species, oysters, in their lease area. DFO refers to adaptive management as a tool that should guide the development of Canada's aquaculture development [68] however makes no mention of how this framework should be specifically applied, or how its particular relevance of climate change. To address this, an adaptive policy framework specific to aquaculture, which acknowledges the unique uncertainties generated by climate change should be created. Adaptive management could be used to address the concerns of farmers recognized in this study, such climate change impacts to farm operations (19), and the potential for stock loss from increased mortality rates (5). Research on the topics could be facilitated through collaboration of industry and the government through extant programs at DFO such as the Aquaculture Collaborative Research and Development Program.

The perspectives identified in this research represent a challenge for policy makers: the need to address the short-term concerns of stakeholders, while also sustainably preserving the longevity of the industry. At a higher level of decision making, the government can promote a sustainable and adaptive industry to climate change through mechanisms such as EAA and adaptive management. This kind of action addresses concerns identified by the Theorist perspective. On a more local scale, (e.g. regional/provincial) concerns of the Pragmatist perspective could be addressed through short-term changes such as lease amendments.

Although this study was conducted on a localized group of stakeholders in Canada, climate change impacts on shellfish aquaculture are a concern at the global scale [2,3]. Localized effects and stakeholder groups may vary; however, the need to integrate perceptions from diverse groups remains the same. The manager-farmer divide identified here between the Theorist and the Pragmatist perspectives has been recognized in many areas of resource management [62]. Further, the struggle of legislative bodies to address both short- and long-term impacts to the aquaculture industry has been recognized on a global scale by the FAO [3]. It is important to consider how the perspective of stakeholders may vary, and how these perspectives fit into local legislative systems.

5. Conclusions

Stakeholders of the bivalve aquaculture industry in Nova Scotia and Prince Edward Island do not feel unanimously about the expected effects of climate change. Three main perspectives were found that defined all stakeholders, and although these perspectives were all defined by more than one stakeholder group, an identifiable gap was seen between farmers and managers, indicating a potential gap between these boundary groups. This disconnect between managers and farmers may be bridged by researchers, who shared perspectives with both groups of stakeholders. Although stakeholders recognized the link between climate change and biological impacts for shellfish, they were generally less certain (or concerned) with the impacts of climate change on farming costs, planning, and practices. As these uncertainties generate risk, government policy should make use of proposed management frameworks such as the ecosystem approach to aquaculture and adaptive management, to incorporate the predicted impacts of climate change, and how this industry can prepare to respond. The nature of these frameworks demands a higher level of integration between social, ecological, and economic systems, and provide potential to use research as a way to integrate farmers into the management process. This research shows the need for policy to consider the impacts of climate change on shellfish farming, both in the short- and long-term, so that farmers can prepare for these impacts.

Declarations of interest

None.

Acknowledgments

This work was completed as part of graduate research at Dalhousie University, Canada. Funding was provided through a graduate NSERC scholarship to Laura Steeves and NSERC Discovery Grant to Ramón Filgueira. Authors would like to thank Jenny Weitzman for her assistance with the Q methodology process.

References

[1] M.L. Zippay, B. Helmuth, Effects of temperature change on mussel, Mytilus, Integr. Zool. 7 (2012) 312–327, https://doi.org/10.1111/j.1749-4877.2012.00310.x.
[2] IPCC (Intergovernmental Panel on Climate Change), Summary for policymakers, in: T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, et al. (Eds.), Climate Change 2013: the Physical Science Basis (Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change), Cambridge University Press, Cambridge, United Kingdom and New York, New York, 2013, pp. 3–29.
[3] S.S. De Silva, D. Soto, Climate change and aquaculture: potential impacts, adaptation and mitigation. Climate change implications for fisheries and aquaculture: overview of current scientific knowledge, FAO Fisheries and Aquaculture Technical Paper 530, 2009, pp. 151–212.
[4] R. Shelmerdine, B. Mouat, R. Shucksmith, The most northerly record of feral Pacific oyster *Crassostrea gigas* (Thunberg, 1793) in the British Isles, BioInvasions Records, vol. 6, 2017, pp. 57–60, , https://doi.org/10.3391/bir.2017.6.1.09.
[5] FAO (Food and Agriculture Organization of the United Nations), Global Aquaculture Production 1950-2015 [Online Query]. Food and Agriculture Organization of the United Nations, (2015) [Accessed November 15th, 2017] Available online at: http://www.fao.org/fishery/statistics/global-aquaculture-production/query/en.
[6] R. Callaway, A.P. Shinn, S.E. Grenfell, J.E. Bron, G. Burnell, E.J. Cook, et al., Review of climate change impacts on marine aquaculture in the UK and Ireland: climate change and marine aquaculture in the UK and Ireland, Aquat. Conserv. 22 (2012) 389–421, https://doi.org/10.1002/aqc.2247.
[7] G.G. Waldbusser, B. Hales, C.J. Langdon, B.A. Haley, P. Schrader, E.L. Brunner, et al., Saturation-state sensitivity of marine bivalve larvae to ocean acidification, Nat. Clim. Change 5 (2014) 273–280, https://doi.org/10.1038/nclimate2479.
[8] R. Filgueira, T. Guyondet, L.A. Comeau, R. Tremblay, Bivalve aquaculture-environment interactions in the context of climate change, Glob. Chang. Biol. 22 (2016) 3901–3913, https://doi.org/10.1111/gcb.13346.
[9] J.S. Diana, H.S. Egna, T. Chopin, M.S. Peterson, L. Cao, R. Pomeroy, et al., Responsible aquaculture in 2050: valuing local conditions and human innovations will be key to success, Bioscience 63 (2013) 255–262, https://doi.org/10.1525/bio.2013.63.4.5.
[10] D.S. Lemmen, F.J. Warren, T.S. James, C.S.L. Mercer Clarke (Eds.), Canada's Marine Coasts in a Changing Climate, Government of Canada, Ottawa, ON, 2016, p. 274.
[11] R. Filgueira, T. Guyondet, L.A. Comeau, J. Grant, Storm-induced changes in coastal geomorphology control estuarine secondary productivity, Earth's Future. 2 (2013) 1–6, https://doi.org/10.1002/2013EF000145.
[12] N. Catto, K. MacQuarrie, M. Hermann, Geomorphic response to Late Holocene climate variation and anthropogenic pressure, northeastern Prince Edward Island, Canada, Quat. Int. 87 (2002) 101–117.
[13] B.L. Bayne, J. Widdows, R.J. Thompson, Physiological integrations, in: B.L. Bayne (Ed.), Marine Mussels, Cambridge University Press, Cambridge, 1976, pp. 261–299.
[14] C. Kittner, H. Riisgård, Effect of temperature on filtration rate in the mussel *Mytilus edulis*: no evidence for temperature compensation, Mar. Ecol. Prog. Ser. 305 (2005) 147–152, https://doi.org/10.3354/meps305147.
[15] C.J. Philippart, H.M. van Aken, J.J. Beukema, O.G. Bos, G.C. Cadée, R. Dekker, Climate-related changes in recruitment of the bivalve *Macoma balthica*, Limnol. Oceanogr. 48 (2003) 2171–2185.
[16] S. Diederich, G. Nehls, J.E.E. van Beusekom, K. Reise, Introduced Pacific oysters (*Crassostrea gigas*) in the northern Wadden Sea: invasion accelerated by warm summers? Helgol. Mar. Res. 59 (2005) 97–106, https://doi.org/10.1007/s10152-004-0195-1.
[17] S.J. Jones, N. Mieszkowska, D.S. Wethey, Linking thermal tolerances and biogeography: *Mytilus edulis* (L.) at its southern limit on the East coast of the United States, Biol. Bull. 217 (2009) 73–85, https://doi.org/10.1086/BBLv217n1p73.
[18] S.J. Jones, F.P. Lima, D.S. Wethey, Rising environmental temperatures and biogeography: poleward range contraction of the blue mussel, *Mytilus edulis* L., in the western Atlantic: *Mytilus edulis* poleward range contraction, J. Biogeogr. 37 (2010) 2243–2259, https://doi.org/10.1111/j.1365-2699.2010.02386.x.
[19] E. Rinde, D.Ø. Hjermann, A. Staalstrøm, Larvae Drift Simulations of the Pacific Oyster in Skagerrak–Influence of Climate Change on Larvae Development, Survival and Dispersal, (2016) [Accessed September 3rd, 2017] Available online at: https://brage.bibsys.no/xmlui/handle/11250/2386876.
[20] R. Filgueira, M.S. Brown, L.A. Comeau, J. Grant, Predicting the timing of the pediveliger stage of *Mytilus edulis* based on ocean temperature, J. Mollus. Stud. 81

(2015) 269–273, https://doi.org/10.1093/mollus/eyu093.
[21] Y. Thomas, S. Pouvreau, M. Alunno-Bruscia, L. Barillé, F. Gohin, P. Bryère, et al., Global change and climate-driven invasion of the Pacific oyster (*Crassostrea gigas*) along European coasts: a bioenergetics modelling approach, J. Biogeogr. 43 (2015) 568–579, https://doi.org/10.1111/jbi.12665.
[22] T. Guyondet, L.A. Comeau, C. Bacher, J. Grant, R. Rosland, R. Sonier, et al., Climate change influences carrying capacity in a coastal embayment dedicated to shellfish aquaculture, Estuar. Coasts 38 (2015) 1593–1618, https://doi.org/10.1007/s12237-014-9899-x.
[23] F. Gazeau, L.M. Parker, S. Comeau, J.-P. Gattuso, W.A. O'Connor, S. Martin, et al., Impacts of ocean acidification on marine shelled molluscs, Mar. Biol. 160 (2013) 2207–2245, https://doi.org/10.1007/s00227-013-2219-3.
[24] V. Montalto, B. Helmuth, P.M. Ruti, A. Dell'Aquila, A. Rinaldi, G. Sarà, A mechanistic approach reveals non-linear effects of climate warming on mussels throughout the Mediterranean sea, Clim. Change 139 (2016) 293–306, https://doi.org/10.1007/s10584-016-1780-4.
[25] N.A. Mazur, A.L. Curtis, Risk perceptions, aquaculture, and issues of trust: lessons from Australia, Soc. Nat. Resour. 19 (2006) 791–808, https://doi.org/10.1080/08941920600835551.
[26] D. Whitmarsh, M.G. Palmieri, Social acceptability of marine aquaculture: the use of survey-based methods for eliciting public and stakeholder preferences, Mar. Pol. 33 (3) (2009) 452–457 https://doi.org/10.1016/j.marpol.2008.10.003.
[27] J. Chu, J.L. Anderson, F. Asche, L. Tudur, Stakeholders' perceptions of aquaculture and implications for its future: A Comparison of the U.S.A. and Norway, Mar. Resour. Econ. 25 (2010) 61–76, https://doi.org/10.5950/0738-1360-25.1.61.
[28] A. Rivera, J. Unibazo, P. León, F. Vásquez-Lavín, R. Ponce, L. Mansur, et al., Stakeholder perceptions of enhancement opportunities in the Chilean small and medium scale mussel aquaculture industry, Aquaculture 479 (2017) 423–431, https://doi.org/10.1016/j.aquaculture.2017.06.015.
[29] D. Etkin, E. Ho, Climate change: Perceptions and discourses of risk, J. Risk Res. 10 (2007) 623–641, https://doi.org/10.1080/13669870701281462.
[30] A. Spence, W. Poortinga, C. Butler, N.F. Pidgeon, Perceptions of climate change and willingness to save energy related to flood experience, Nat. Clim. Change 1 (2011) 46–49, https://doi.org/10.1038/nclimate1059.
[31] S.L. Jørgensen, M. Termansen, Linking climate change perceptions to adaptation and mitigation action, Clim. Change 138 (2016) 283–296, https://doi.org/10.1007/s10584-016-1718-x.
[32] K. Bacher, A. Gordoa, E. Mikkelsen, Stakeholders' perceptions of marine fish farming in Catalonia (Spain): A Q-methodology approach, Aquaculture 424 (2014) 78–85, https://doi.org/10.1016/j.aquaculture.2013.12.028.
[33] A. Buanes, S. Jentoft, G. Runar Karlsen, A. Maurstad, S. Søreng, In whose interest? An exploratory analysis of stakeholders in Norwegian coastal zone planning, Ocean Coast Manag. 47 (2004) 207–223.
[34] S. Sevaly, Involving stakeholders in aquaculture policy-making, planning and management, in: R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery, J.R. Bangkok Arthur (Eds.), Aquaculture in the Third Millennium. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, NACA, Bangkok and FAO, Rome, 2001, pp. 83–93. Thailand, 20-25 February 2000.
[35] T. Altintzoglou, W. Verbeke, F. Vanhonacker, J. Luten, The image of fish from aquaculture among Europeans: impact of exposure to balanced information, J. Aquat. Food. (2010).
[36] J. Fernández-Polanco, L. Luna, Analysis of perceptions of quality of wild and cultured seabream in Spain, Aquac. Econ. Manag. 14 (2010) 43–62.
[37] S. Freeman, E. Vigoda-Gadot, H. Sterr, M. Schultz, I. Korchenkov, P. Krost, D. Angel, Public attitudes towards marine aquaculture: a comparative analysis of Germany and *Israel*, Environ. Sci. Pol. 22 (2012) 60–72.
[38] C. Bacher, J. Grant, A. Hawkins, J. Fang, P. Zhu, P. Duarte, Modeling the effect of food depletion on scallop growth in Sungo Bay (China), Aquat. Living Resour. 16 (2003) 10–24.
[39] J. Weitzman, M. Bailey, Perceptions of aquaculture ecolabels: A multi-stakeholder approach in Nova Scotia, Canada, Mar. Pol. 87 (2018) 12–22, https://doi.org/10.1016/j.marpol.2017.09.037.
[40] N. Handisyde, T.C. Telfer, L.G. Ross, Vulnerability of aquaculture-related livelihoods to changing climate at the global scale, Fish Fish. 18 (2017) 466–488, https://doi.org/10.1111/faf.12186.
[41] DFO (Department of Fisheries and Oceans Canada), Socio-economic Impact of Aquaculture in Canada, (2012) [Accessed October 10th, 2017] Available online at: http://www.dfo-mpo.gc.ca/aquaculture/sector-secteur/socio/index-eng.htm#_5.0.
[42] NSDFA (Nova Scotia Department of Fisheries and Aquaculture), Aquaculture Strategy: Creating Sustainable Wealth in Rural and Coastal Nova Scotia, (2015) [Accessed October 10th, 2017] Available online at: http://novascotia.ca/fish/documents/NS-Aquaculture-Strategy.pdf..
[43] DFO (Department of Fisheries and Oceans Canada), Aquaculture: Production quantities and values, [Accessed August 28th, 2017] Available online at: http://www.dfo-mpo.gc.ca/stats/aqua/aqua15-eng.htm.
[44] Government of Nova Scotia, Budget 2017-2018, (2017) [Accessed November 9th, 2017] Available online at: https://novascotia.ca/budget/.
[45] Statistics Canada, Unemployment Rate Monthly, Canada and Provinces, Unadjusted. Economics and Statistics Branch, Newfoundland and Labrador, 2016.
[46] V.S. Saba, S.M. Griffies, W.G. Anderson, M. Winton, M.A. Alexander, T.L. Delworth, et al., Enhanced warming of the Northwest Atlantic Ocean under climate change: Northwest Atlantic enhanced warming, J. Geophys. Res Oceans. 121 (2016) 118–132, https://doi.org/10.1002/2015JC011346.
[47] P.N. Rudell, M.L. Miller, Human perceptions and attitudes regarding geoduck aquaculture in Puget sound, Washington: A Q-method approach, J. Shellfish Res. 31 (2012) 342–343.
[48] S. Shackley, R. Deanwood, Stakeholder perceptions of climate change impacts at the regional scale: Implications for the effectiveness of regional and local responses, J. Env. Plan. Man. 45 (2002) 381–402, https://doi.org/10.1080/09640560220133414.
[49] S.R. Brown, Political Subjectivity: Applications of Q Methodology in Political Science, Yale University Press, New Haven, 1980.
[50] S.R. Brown, Q Methodology and qualitative research, Qual. Health Res. 6 (1996) 561–567, https://doi.org/10.1177/104973239600600408.
[51] R.M. Cross, Exploring attitudes: The case for Q methodology, Health Educ. Res. 20 (2005) 206–213 http://doi.org/10.1093/her/cyg121.
[52] T.C. Du Plessis, A Theoretical Framework of Corporate Online Communication: A Marketing Public Relations (MPR) Perspective, University of South Africa, Pretoria, 2005 [dissertation] [South Africa].
[53] R. Likert, A Technique for the Measurement of attitudes. Archives of Psychology vol. 22, New York University, New York, 1932, pp. 5–55.
[54] P. Schmolck, The QMethod Page: PQMethod Software, (2017) [Accessed September 20th, 2017] Available online at: http://schmolck.userweb.mwn.de/qmethod/.
[55] T. Webler, S. Danielson, S. Tuler, Using Q Method to Reveal Social Perspectives in Environmental Research, Social and Environmental Research Institute, Greenfield MA, 2009 [Accessed September 20th, 2017] Available online at: http://www.seri-us.org/sites/default/files/Qprimer.pdf.
[56] B. McKeown, D. Thomas, Q Methodology, second ed., Sage Publications, Newbury Park, Ca, 2013.
[57] R. Curry, J. Barry, A. McClenaghan, Northern visions? Applying Q methodology to understand stakeholder views on the environmental and resource dimensions of sustainability, J. Environ. Plann. Manag. 56 (2013) 624–649 https://doi.org/10.1080/09640568.2012.693453.
[58] S. Watts, P.H.D. Stenner, Doing Q methodology: Theory, method and interpretation, Qual. Res. Psychol. 2 (2005) 67–91 https://doi.org/10.1191/1478088705qp022oa.
[59] Stantec, Road Map for Aquaculture Investment in Nova Scotia, (2009) File no. 1048755.
[60] M. Kaiser, S. Steas, Uncertainties and values in European aquaculture: Communication, management, and policy issues in times of "changing public perception", Aquacult. Int. 10 (2002) 469–490.
[61] J. Bandola-Gill, C. Lyall, Knowledge Brokers and Policy Advice in Policy Formulation, Handbook of Policy Formulation, Edward Elgar Publishing Ltd, 2017.
[62] B.H. Macdonald, S.S. Soomai, E.M. De Santo, P.G. Wells, Science, Information, and Policy Interface for Effective Coastal and Ocean Management, CRC Press, 2016.
[63] S.A. Jones, B. Fischhoff, D. Lach, Evaluating the science-policy interface for climate change research, Clim. Change 43 (1999) 581–599.
[64] G. Krause, C. Brugere, A. Diedrich, M.W. Ebeling, S.C.A. Ferse, E. Mikkelsen, et al., A revolution without people? Closing the people–policy gap in aquaculture development, Aquaculture 447 (2015) 44–55, https://doi.org/10.1016/j.aquaculture.2015.02.009.
[65] M. Charlton, Ensuring the Long-Term Success of Nova Scotia's Oyster Sector, Dalhousie News, 2017 [Accessed November 8th, 2017] Available online at: https://www.dal.ca/news/2017/06/14/ensuring-the-long-term-success-of-nova-scotia-s-oyster-sector-.html.
[66] Z. Doubleday, S. Clarke, X. Li, G. Pecl, T. Ward, S. Battaglene, et al., Assessing the risk of climate change to aquaculture: a case study from south-east Australia, Aquacut. Env. Interac. 3 (2013) 163–175, https://doi.org/10.3354/aei00058.
[67] C. Shelton, Climate change adaptation in fisheries and aquaculture – compilation of initial examples, FAO Fisheries and Aquaculture Circular No. 1088, vol. 34, FAO, Rome, 2014.
[68] DFO (Department of Fisheries and Oceans Canada), Aquaculture policy framework, [Accessed October 20th, 2017] Available online at: http://www.dfo-mpo.gc.ca/aquaculture/ref/APF-PAM-eng.htm.
[69] Building an ecosystem approach to aquaculture, in: D. Soto, J. Aguilar-Manjarrez, N. Hishamunda (Eds.), FAO/Universitat de les Illes Balears Expert Workshop. 7–11 May 2007, Palma de Mallorca, Spain. FAO Fisheries and Aquaculture Proceedings. No. 14, Rome, FAO, 2008221p.
[70] C. Brugère, J. Aguilar-Manjarrez, M.C.M. Beveridge, D. Soto, The ecosystem approach to aquaculture 10 years on - a critical review and consideration of its future role in blue growth, Reviews in Aquaculture, 2018 https://doi.org/10.1111/raq.12242.
[71] L.E. Steeves, R. Filgueira, T. Guyondet, J. Chassé, L. Comeau, Past, present, and future: Performance of two bivalve species under changing environmental conditions, Front. Mar. Sci. 5 (2018), https://doi.org/10.3389/fmars.2018.00184.
[72] C.S. Holling, United Nations Environment Programme (Eds.), Adaptive Environmental Assessment and Management. Laxenburg, International Institute for Applied Systems Analysis; Wiley, Austria, Chichester, New York, 1978.
[73] G. Peterson, G.A. De Leo, J.J. Hellmann, M.A. Janssen, A. Kinzig, J.R. Malcolm, et al., Uncertainty, climate change, and adaptive management, Conserv. Ecol. 1 (2) (1997) 4.
[74] B. Myrand, H. Guderley, J.H. Himmelman, Reproduction and summer mortality of blue mussels *Mytilus edulis* in the Magdalen Islands, southern Gulf of St. Lawrence, Mar. Ecol. Prog. Ser. (2000) 193–207.